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**A COMPUTER SYSTEM TO ANALYZE SHOWERS
IN NUCLEAR EMULSIONS**

Center Director's Discretionary Fund Final Report

By C. A. Meegan, W. F. Fountain, and F. A. Berry, Jr.

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16. ABSTRACT This report describes a system to rapidly digitize data from showers in nuclear emulsions. A TV camera views the emulsions through a microscope. The TV output is superimposed on the monitor of a minicomputer. The operator uses the computer's graphics capability to mark the positions of particle tracks. The coordinates of each track are stored on disk. The computer then predicts the coordinates of each track through successive layers of emulsion. The operator, guided by the predictions, thus tracks and stores the development of the shower. The system provides a significant improvement over purely manual methods of recording shower development in nuclear emulsion stacks.					
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TECHNICAL MEMORANDUM

A COMPUTER SYSTEM TO ANALYZE SHOWERS IN NUCLEAR EMULSIONS

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I. INTRODUCTION

Nuclear emulsions have long been used to record the trajectories of high energy particles in a variety of experiments. Emulsions used for this purpose are similar to photographic film, except they are thicker and contain a higher proportion of silver halide. After exposure to high energy charged particles, the nuclear emulsions are developed, then scanned microscopically. One disadvantage of this technique, as compared to electronic detection of charged particles, is the laborious and error-prone process of scanning many emulsions by eye.

The Japanese-American Cooperative Emulsion Experiment (JACEE) is a collaboration of scientists from several institutions in the United States and abroad whose purpose is to study interactions of high energy cosmic rays. The collaboration has flown several instruments on high altitude balloons since 1979. One goal of these observations is to study the properties of matter at the extremely high energy densities that result when high energy, heavy nuclei collide. Theoretical considerations indicate that a new form of matter, called the quark-gluon plasma, may be formed in such a collision. Further details of JACEE can be found in Burnett et al. [1].

A total of approximately 2000 nuclear emulsion plates have been exposed over the duration of the JACEE collaboration. The analysis of the JACEE data requires scanning these emulsions to locate and characterize high energy interactions. This requires recording the positions of a large number of tracks through many emulsion layers. The purpose of this research was to develop a computer-assisted procedure to rapidly record track positions.

In the system developed, a microscopic image of the emulsion is superimposed on a computer monitor. The operator positions a cursor at the position of a track, which is then stored on disk. After a set of tracks is thus recorded, the computer predicts the locations of the tracks in the next emulsion layer. This semi-automated system makes use of the computer's capabilities for the tedious data recording and the human operator's adeptness for pattern recognition. It would not be practical, within the constraints of this project, to attempt to fully automate this task, since this would require a high level of artificial intelligence in the computer. The limited automation we have incorporated, however, should significantly reduce the time required to scan the emulsions manually.

Systems similar to ours have been developed by several research groups [2-4]. A unique feature of our system is the prediction of track positions in successive layers of emulsion, allowing the operator to follow individual tracks and obtain a complete picture of shower developments.

II. DESCRIPTION

A. Hardware

The hardware for the microscope digitizer system is based on an Amiga computer system. This system is interfaced to a Nikon Measurescope Model II microscope. The trinocular microscope has both eyepieces and a television camera attached. A diagram of the system is shown in Figure 1. A photograph is shown in Figure 2.

The Amiga computer system consists of a color monitor, keyboard, main unit with disk drive, and 3½- and 5¼-in. external disk drives. This system uses 512 kilobytes of RAM with 256 kilobytes of reserved system memory. A mouse is used as a graphics input device. Output from the computer may be stored on the disk or printed on the Epson RX-80 printer.

The Amiga computer was chosen because of its speed, graphics capabilities, and ease of programming. The Amiga uses a Motorola 68000 processor along with two co-processors, a blitter, and a copper. The blitter co-processor handles the graphics tasks and greatly improves the speed at which graphics can be processed and displayed. The copper is the memory management co-processor and handles all the I/O and DMA functions. The Amiga has a screen resolution of 640 by 400 pixels. For this project, we are presently using 640 by 200 pixel graphics to eliminate a flicker problem in the higher resolution display.

A Hitachi Nuvicon CCTV camera model HV-17TV is used to view the emulsion through the microscope. The signal is fed through a Colorado Video Sync Stripper model 302-1 to synchronize the video to the computer output. The graphics output of the computer and the video from the camera are then combined and fed to a monitor.

A Fairchild model 3000 CCD camera is also available. However, as described below, interface difficulties have thus far prevented the use of this camera.

B. Track Geometry

Figure 3 shows a diagram of the geometry of a particle track passing through the emulsion stack. Only two emulsion plates are shown. Each emulsion plate in the stack consists of two emulsion layers of thickness t , covering the surfaces of a substrate of thickness d . Successive emulsion plates are separated at distance ℓ by passive spacer material. The tracks are visible only in the emulsion, as shown by the heavy lines in Figure 3.

By small changes in the focus, a track can be followed visually from the position $X_1(i)$ to the point $X_2(i)$ in the top layer of emulsion i . The coordinates of the track at the bottom layer are predicted by the formulae:

$$X_3(i) = X_2(i) + (d/t) [X_2(i) - X_1(i)] ,$$

$$X_4(i) = X_3(i) + X_2(i) - X_1(i) \quad ,$$

and similar formulae for the Y axis.

The predictions of the track position in the next $(i + 1)$ layer of emulsion use a similar procedure. However, the most accurate prediction is obtained using the points $X_2(i)$ and $X_3(i)$ due to distortions within the emulsion layer. The predicted position of $X_1(i + 1)$ is given by the formulae:

$$X_1(i + 1) = X_3(i) + [(\ell + t)/d] [X_3(i) - X_2(i)] \quad ,$$

$$X_2(i + 1) = X_1(i + 1) + (t/d) [X_3(i) - X_2(i)] \quad ,$$

and similar formulae for the Y axis.

Typical values for the various thicknesses are $t = 75$ microns, $d = 800$ microns, and $\ell = 2000$ microns.

C. Software

The software performs the following functions: (1) allows the user to enter the positions of tracks in the top layer of an initial emulsion plate (X_1 , Y_1 , X_2 , and Y_2) and stores those positions to a disk file; (2) predicts the position of tracks on the bottom emulsion layer of the emulsion plate (X_3 , Y_3 , X_4 , and Y_4) and displays them on the monitor; (3) allows the user to enter the actual positions of the predicted tracks and store them in a disk file; and (4) predicts the position of tracks in a new emulsion plate using the positions recorded from a previous plate. The software labels each track so it can be followed through the emulsion stack. The software also allows predicted tracks to be marked as missing, after which their positions are no longer predicted to subsequent emulsion plates. As an aid to data analysis, a track can be marked as "heavy," implying a large number of unresolved particles.

All software for this project is written in Amiga BASIC. This language is interpreted, but is executed rapidly enough to keep ahead of the human operator. The language resembles Pascal in its lack of line numbers and in the use of structured commands.

The program is loaded from the workbench environment of the Amiga computer. Almost all of the interaction is done with the mouse. The keyboard is used only to type specific file names and other alphanumeric information. The program uses pull-down menus to accomplish all tasks. This feature creates a user-friendly and efficient environment.

First, the user must tell the computer which objective is in use on the microscope. This is necessary because different objective lenses correspond to different scales on the monitor. Then the

user is given a choice of either loading a previous unfinished emulsion layer file or starting a new layer. Using the mouse, cursors are positioned at the beginning and end of each track to be digitized. The computer automatically records and stores the information for the position of each track along with characteristics of the individual tracks, such as a heavy or new track. When the user has finished digitizing a layer, the computer writes a disk file for that layer and automatically predicts the pattern for the next layer. The predictions consist of a display of the track pattern expected in the next layer. The user then positions the microscope stage so that the tracks match the predictions. Each predicted track is highlighted in turn as the user enters the actual coordinates of the track by positioning the cursor. By selecting from a pop-up menu, the user can mark a track as heavy or skip a missing track. If a predicted track should fall outside the field of view, the computer calculates a new microscope stage position and notifies the operator to move the stage. After moving the stage, the operator inputs the new stage position. Predictions are then recalculated for the new stage position and input of track positions resumes. The program keeps track of all stage movements so that all track positions stored on disk are referenced to a single origin. If a new track is encountered, the operator may add that track to the list after the predicted tracks are completed.

D. Problems Encountered

Distortion in Camera

The Nuvicon camera, being an analog device, introduces a noticeable amount of distortion into the picture displayed on the monitor. This "pincushion effect" causes line segments in the outer edges to appear longer than in the center of the screen. A CCD camera, on the other hand, digitally breaks the image into discrete pixels and preserves the length of each line segment. Distortion will cease to be a problem when the CCD camera is successfully incorporated into the system.

Fairchild Camera Sync Problem

The Fairchild model 3000 CCD camera system was advertised as permitting external synchronization by another video source. It was later found that the only external sync pulse the camera would accept was that of another Fairchild camera. This camera cannot be properly synchronized to the Colorado Video Sync Separator. A scheme where the computer is synchronized to the camera is being pursued at this time.

Emulsion Stability

A number of factors combine which impose the limiting precision of the software track predictions. Cumulative X and Y position errors are introduced during a measurement period by local variations in temperature and humidity causing distortions of the nuclear film. Combined, these effects give as much as a ± 30 micron drift in a given track position over a measurement period of about 40 min, as well as substantial defocussing of the image (i.e., Z-axis drift). Techniques have been devised to minimize these effects to a negligible level. These include allowing sufficient system warm-up time to achieve thermal stabilization of the optical path from lamp heating. Rigid positive control of room temperature and humidity and the placing of mechanical shields to prevent air currents from flowing across the film surface from the operator's breathing and/or body motions. These techniques have reduced these types of errors to approximately ± 1 micron.

A major distortion in the track paths found in some plates is a result of differential shrinkage throughout the thickness of the emulsion layer, and occurs during the development and drying procedure. The effect is to produce a curvature of the tracks which are not indicative of the true path of the particle. This distortion is permanent after processing and is presently circumvented by skipping those plates with this effect.

Alignment

A separate alignment problem involves the precise placement of each successive film sheet on the microscope measurement table in such a way as to maintain proper alignment of individual tracks throughout the depth of the film stack. This is done using precision-made adjustable mechanical stops on the X,Y measurement table, but relies on the accuracy of the base material fabrication and packaging of the original film stack. The best vertical registration achieved so far in packaging a given JACEE experiment stack is only slightly better than 150 micrometers. This means that any prediction from one plate to the next could be from 0 to 150 microns off in any axial direction for all measured tracks. As predictions are made from one layer to the next, the starting points of a set of measured tracks within a single microscope field of view (from 150 to 500 microns, depending on the optics) are displayed in the TV monitor to provide a visual prediction pattern to the operator which can be quickly matched and realigned with the superimposed real image pattern of the next layer by manual fine adjustment of the microscope stage position. Any new tracks that appear are easily spotted and are coded from the keyboard as their X and Y positions are entered. Any terminated or lost tracks are automatically identified in the software. Tracks falling outside the boundary of a single microscope FOV are located as described previously.

III. SUMMARY AND CONCLUSIONS

A. Summary

This study has shown how a relatively inexpensive system for digitizing tracks in nuclear emulsions can be implemented. The total cost of equipment was about \$6,700, and the manpower required was about 2 manyears. The system is presently in use to store track data. The full potential of the system will be realized when the improvements discussed below can be incorporated. It is expected that an improvement of a factor of 5 in the time required for analyzing emulsion data can be achieved.

The most significant limitations of the system are: (1) even slightly inclined tracks typically lead to predictions outside the field of view, resulting in a great deal of stage motion; and (2) the accuracy of the predictions is limited by distortions in the emulsion layers, requiring some visual hunting for the actual track around the predicted track.

B. Future Work

The next innovation to the software will add a reference track to the file so that the successive layers of the emulsion may be tracked without introducing cumulative errors due to inaccuracies in the tracks and reference marks on the emulsion. This should allow the operator to declare the central core of the shower as his reference and to rely on this core as his reference.

An important hardware improvement is to complete the incorporation of the CCD camera into the system. This will eliminate the distortion problems described earlier.

The next hardware innovation is a "frame grabber" to store five successive slices (focus depths) of the emulsion in the computer and electronically "focus down" to these slices instead of having to manually adjust the focus of the microscope. This feature should greatly improve speed and convenience.

C. Other Uses

The hardware system developed has wide applications to other tasks requiring digitization of microscopic images. Adapting the system to new applications is just a matter of writing new software.

A possible application, very similar to the analysis of emulsion plates, is the analysis of CR-39 plates. CR-39 is a plastic (Aryldiglycol carbonate, $C_{12}H_{18}O_7$) that is damaged by the passage of highly charged cosmic ray particles. After "etching" by a high temperature solution of sodium hydroxide, the particle paths become apparent as small pits. With appropriate new software, this system could be used to digitize the position and diameter of the etch pits.

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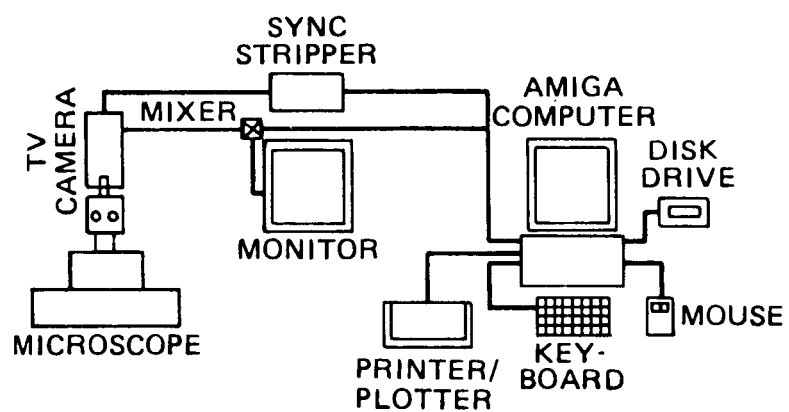


Figure 1. Block diagram of automated emulsion analysis system.

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Figure 2. Photograph of system in operation.

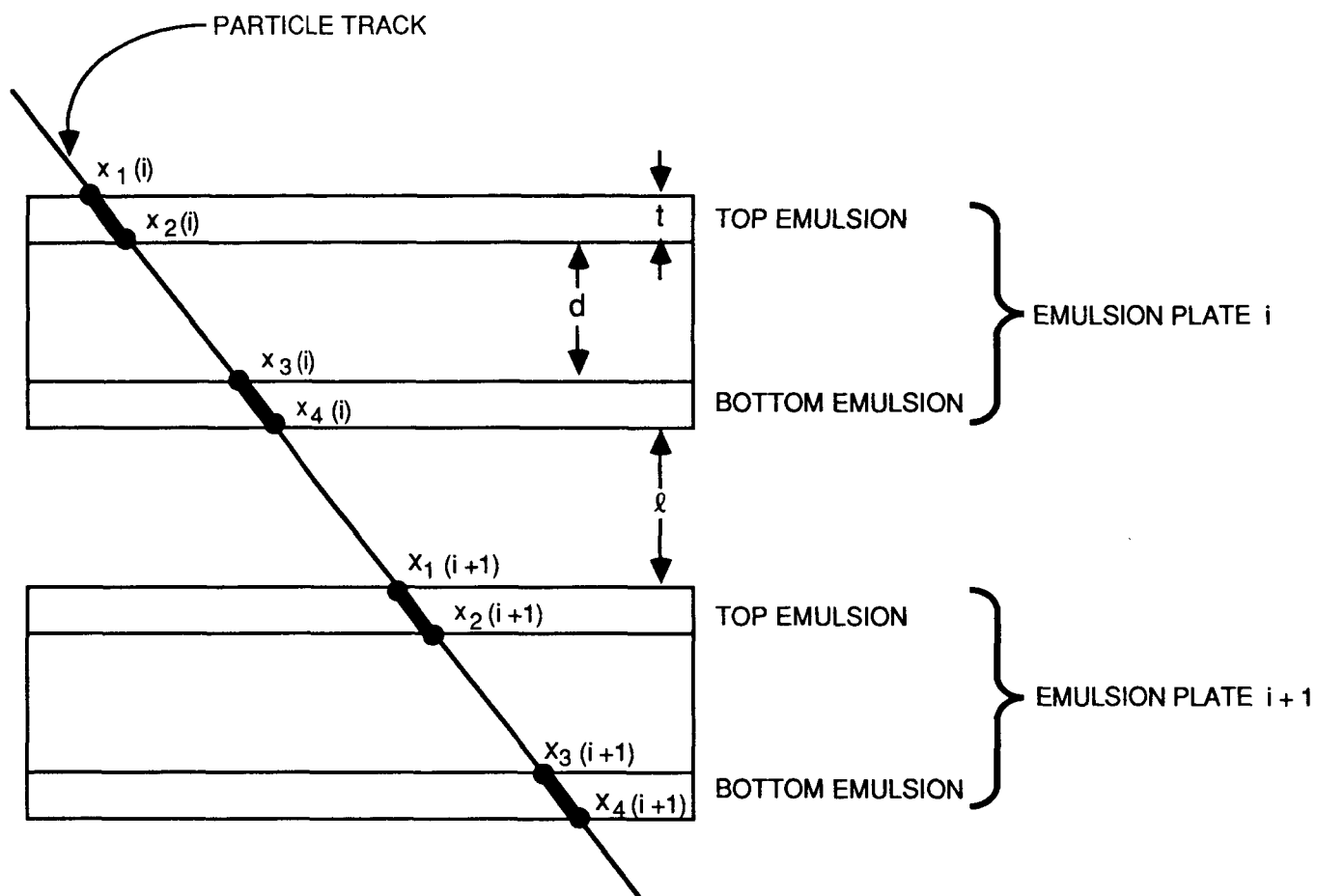


Figure 3. Emulsion geometry.

APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

E. Tandberg-Hanssen

E. TANDBERG-HANSEN

Director, Space Science Laboratory